Information to Support the Human Performance Modeling of a B757 Flight Crew during Approach and Landing:

RNAV

Prepared for:
National Aeronautics and Space Administration
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Table of Contents

1 Introduction

The NASA Aviation System Program (AvSP) was created to perform research and develop technology to reduce the rate of fatal aircraft accidents in the US. Under AvSP, the System-Wide Accident Prevention project uses current knowledge about human cognition to develop mitigation strategies to address current trends in aviation accident and incident profiles. System-Wide Accident Prevention is comprised of four elements, one being Human Performance Modeling (HPM). The objective of the HPM element is to develop predictive capabilities to identify likely performance improvements and/or error vulnerabilities in human/system operation. For FY02, this element is investigating the application of HPM to predict the human performance of flight crews utilizing the Synthetic Vision System (SVS) in the cockpit. SVS depicts a clear, 3-dimensional, out-the-cockpit view of terrain, obstacles, runways, etc. to the pilot, regardless of the actual visibility or weather conditions. It also displays a graphical path for the flight crew to follow.

The first step in the FY02 SVS modeling effort is to create a baseline human performance model of the flight crew *without* SVS. In other words, the baseline model represents today's flight deck equipment and operations. NASA decided that the flight deck for this HPM effort would be the Boeing 757. This decision was driven by the fact that SVS flight tests using a NASA-owned B757 have been conducted. The data collected from the flight tests may be used for comparison with the HPM predictions. The NASA HPM element directed the FY02 effort to focus on the approach and landing phases of flight. Indeed, improved pilot situational awareness of terrain, obstacles and the runway environment during approach and landing is expected to be one of the biggest benefits of SVS.

Micro Analysis and Design delivered the initial report, "Information to Support the Human Performance Modeling of a B757 Flight Crew during Approach and Landing", (Leiden et al, 2002), in March. The report contains the task analysis for an ILS-based approach and landing *without* SVS and was intended to contain the information for the baseline modeling effort. The next report, "Information to Support the Human Performance Modeling of a B757 Flight Crew during Approach and Landing: SVS Addendum", (Keller & Leiden, 2002), was delivered in May. The SVS addendum provided the background information and task analysis to support the modeling of the approach and landing *with* SVS. Although the ILS-based approach and landing is commonly used in the industry and is well suited for the baseline modeling effort, circumstances have conspired to support the presentation of an option for the baseline modeling efforts.

As described in both the previous two documents, NASA Ames planned to execute a simulator-based experiment to provide additional data to the modeling teams. The experimental plan called for pilots to execute simulated approach and landings with and without SVS support. The baseline condition was to have been an ILS supported approach. However, difficulties with the simulator limited the baseline case to an RNAV or area navigation approach. Due to cue and task differences between the two types of approaches, the modeling teams may not be able to use the results of the simulator experiment with the information provided in the ILS-based initial report. With this in mind, Micro Analysis and Design was asked to rewrite the initial report based on the RNAV system. This document contains the background information and task analysis for an approach and landing using RNAV.

2 Objective

The objective of this research was to provide the FY02 HPM teams with the necessary information to model the flight crew of a B757 during the approach and landing phases of flight. The first report documented the background information and task analysis of the current B757 approach and landing process as it is currently performed by commercial pilots using ILS. The second was an addendum that provided additional information and task analysis data for pilots using SVS for approach and landing. This document contains the background and task analysis information for approach and landing using RNAV. It is assumed that our audience has read the first document and has a basic understanding of the approach and landing sequence as it applies to a B757 aircraft as well as a basic understanding of the instrument landing system. Much of the background material describing the ILS has been left in this rewrite and the RNAV approach is described by comparing it to the ILS approach. We have attempted to create a document that will stand-alone but have tried to limit the replication of information from the first document to only that which was deemed necessary to explain the differences between ILS and RNAV. As such, some sections from the initial document have been included and/or updated while others have been removed.

Section 4.1 has been added to describe the Area Navigation system. Section 4.2.1 and 4.2.2 describing the ILS have been reduced somewhat but the content has not changed substantially from the original document. Section 4.2.3 describes the RNAV approach. Sections 4.3 and 4.4 have remained virtually unchanged. Section 4.5 describing the controls, instrumentation and displays contains one important change related to the altitude setting dial on the Mode Control Panel. Section 4.6 provides specifics on the flight modes used during an RNAV approach. Section 5 presents the detailed task analysis and contains substantive changes throughout the section.

3 Technical Approach

The first step in this research was to develop background information related to the RNAV system. Our previous literature search efforts proved to contain sufficient information about the RNAV systems to support our needs. The next step was to interview an SME who had experience with RNAV approaches. We were fortunate to be able to use the same pilot we had interviewed for the SVS material. He is a current captain and flight instructor for United Airlines.

The SME indicated that RNAV approaches are very rare but was able to provide sufficient information to support this task analysis. The approach scenario used for the task analysis in Section 5 is based on the combination of an actual RNAV approach, relevant procedures from other similar approaches and the experience of the SME.

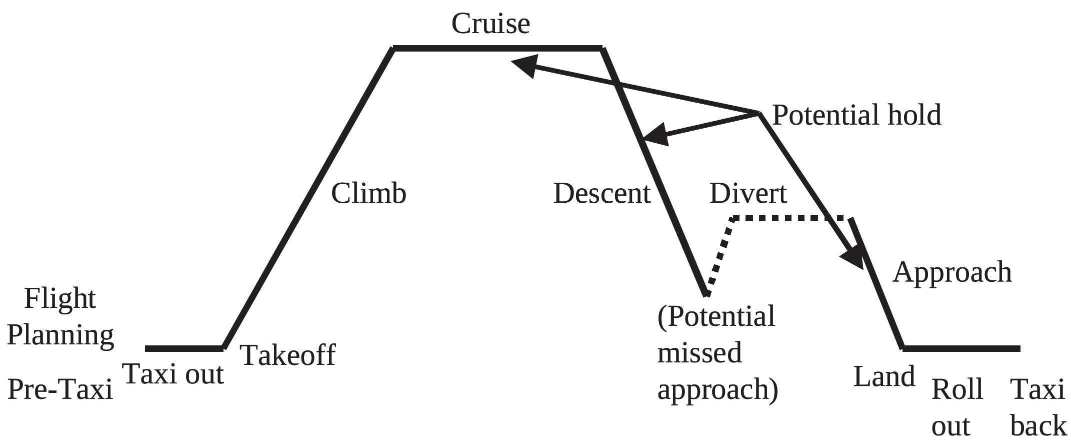
The information collected from both the literature review and the SME was integrated and then decomposed into five topics:

- Background information about the aviation domain, with an emphasis on approach/landing and the B757 flight deck and a comparison of ILS and RNAV (Section 4)
- Behavioral task analysis of the approach and landing (Section 5.1-5.2)
- Review of the approach used for the simulator experiments (Section 5.3)
- Discussion of errors associated with approach and landing (Section 5.4)

4 Background Information

Although this research is focused on the B757, the information presented here applies to all air transport carriers. Air transport carriers (e.g., airlines and cargo carriers) are required to file instrument flight rules (IFR) flight plans. Aircraft on IFR flight plans are required to follow air traffic control (ATC) directives. In return, ATC keeps aircraft safely separated, both in the air and on the ground.

This research focuses on the approach and landing phases of flight. Figure 1 shows the relationship of these phases to the other phases of *normal* flight (adapted from Alter &



Regal, 1992).

Figure 1. Normal phases of flight

Although the missed approach and subsequent divert phases of flight are shown in Figure 1, the occurrence is rare amongst professional pilots. Two of the originally interviewed SMEs estimated the occurrence of missed approaches to be about one missed approach per year per pilot or, based on 20 landings per month per pilot, 1 missed approach per 240 landings. Similarly, the hold phase of flight, which can be requested by air traffic control during the cruise, descent, or approach phases of flight, has become less common in recent years due to a more strategic methodology for spacing and sequencing arriving aircraft. That said, missed approaches and holds are still considered phases of normal flight. This is in contrast to emergency situations, which are abnormal and outside the scope of this research.

4.1 Area Navigation

Area Navigation (RNAV) is the system used by commercial aircraft to navigate during most phases of flight. Several different navigation systems both internal and external to the aircraft are used to determine the aircraft's location and the automated flight systems follow a flight path preprogrammed into the Flight Management Computer (FMC). The different navigation systems typically include the Inertial Navigation System (INS), various ground-based radio signal navigation systems, the Global Positioning System (GPS) and different altimeters. The following are short descriptions of each of these systems:

<u>Inertial Navigation System (INS)</u>

The INS is an internal aircraft system that uses accelerometers to measure changes in the speed and direction. Provided that an accurate starting location has been input into the system at the beginning of a flight, the INS is able to determine an accurate location for the aircraft at any point during the flight and is independent of any system external to the aircraft.

<u>Ground-based Radio Signal Navigation</u>

There are a variety of systems comprised of ground-based transmitters that are used by the aircraft's systems to calculate location and speed. These include the VORTAC, LORAN-C and VLF/OMEGA systems. They all work by transmitting radio signals in various ways that can be used to calculate distance and direction from the transmitter to the aircraft.

<u>Global Positioning System (GPS)</u>

GPS functions basically the same as the ground-based systems except that the signals are transmitted by orbiting satellites. Aircraft equipped with GPS receivers can calculate their location independent of the ground-based or inertial guidance systems.

<u>Altimeters</u>

Aircraft are equipped with altimeters that function based on the relative air pressure. They are generally pressure corrected to measure the altitude above mean sea level (MSL). Radio altimeters, on the other hand, measure the absolute distance to the ground by transmitting a signal from the aircraft to the ground and measuring the change in the reflected signal. While the pressure-based altimeter is used during most phases of flight, the radio altimeter is primarily used during the approach and landing phases to measure the exact distance above ground level (AGL).

Area navigation is a function of a combination of several of these systems. The aircraft location is determined based on the combined information from each independent system. In this way, the systems function as double checks for each other. While each aircraft may not be equipped with each navigation system (some don't have GPS for instance) each is equipped with a combination of these systems sufficient to determine its location to the required level of accuracy.

Prior to takeoff, the pilots program the planned flight path into the Flight Management Computer (FMC). The flight path is defined by a series of waypoints between the takeoff and landing locations. Each waypoint is usually associated with a change in heading and/or elevation. The goal is to navigate the aircraft to the next (active) waypoint. The guidance systems within the aircraft combine the location information from the RNAV systems with the planned flight path from the FMC to either provide instructions to the pilots or to produce control inputs with the automated flight systems required to travel along the path to the active waypoint. This combination of navigation, guidance and automation is usually used to get the aircraft from a point shortly after the takeoff phase through climb, cruise and descent to the approach phase. For the approach phase, the crew has a choice of navigation systems based on the visibility, available navigation equipment and approach procedures for a specific runway. The next section will discuss the approach phase of flight and how two different systems, ILS and RNAV, can be used for instrument approaches.

4.2 Approach Phase of Flight

The approach phase begins at the bottom of descent and ends just prior to the flare in the landing phase. During an instrument approach, pilots of air transport carriers must follow the instrument approach procedures regardless of visibility. Instrument approach procedures have been meticulously designed to transition aircraft safely from the en route airway structure to the arrival airport by specifying the heading and minimum altitude allowed to avoid both terrain and nearby air traffic patterns. This is typically done in three segments. Since the segment description depends on the type of approach, the segments will be described in more detail in Section 4.2.2.

Instrument approaches are classified into two types – nonprecision and precision. The difference is determined by the type of navigation aids available at the airport as well as the corresponding instrumentation available on the flight deck. The B757 is equipped with a full range of instrumentation to support virtually all types of nonprecision and precision approaches. A nonprecision approach provides lateral guidance and specific altitudes for the pilot to fly whereas a precision approach provides precise lateral and vertical guidance. ILS approaches are considered to be precision while RNAV approaches are considered non-precision. The next three sections will describe the ILS, the ILS category 1 approach and the RNAV approach respectively.

4.2.1 Instrument Landing System

The instrument landing system consists of three types of transmitters – the localizer, the glide slope, and marker beacons (Nolan, 1994). The **localizer** provides lateral guidance aligned with the runway centerline. The localizer antenna sends a VHF signal that is modulated with a 90 Hz tone and 150 Hz tone corresponding to left and right of centerline, respectively. If the localizer receiver on the flight deck senses that the tones are of equal strength, then the aircraft is aligned with the runway centerline. If the 90 Hz tone dominates, then the aircraft is left of centerline and the aircraft must turn to the right to return to the centerline. Likewise, if the 150 Hz tone dominates, the aircraft is right of centerline. The localizer signal is transmitted at 35 degrees right and left of centerline and is about 7 degrees in height (i.e., starts at level ground and arcs to 7 deg). Between 10 and 25 nm from the antenna, the signal is only certified to be accurate within 10 degrees of right and left of centerline.

The **glide slope** provides vertical guidance to direct the aircraft along a glide path (typically 3 degrees) that will intersect with the ground about 1000 ft from the approach end of the runway. The glide slope antenna sends a UHF signal that is modulated with a 90 Hz tone and 150 Hz tone. If the 90 Hz signal dominates, the aircraft is above the glide slope. The aircraft needs to fly lower to pick up the nominal glide slope. Similarly, if the 150 Hz signal dominates, the aircraft is below the glide slope. Although 3 degrees is a typical glide slope, false glide slopes, due to a reflection of the signal off the ground, can occur at around 9 degrees. The transmission of the glide slope signal is much narrower than the localizer. The glide slope signal, centered about the 3 degree glide slope, is 3 to 6 degrees wide and roughly 1.4 degrees high. A glide slope crossing altitude is specified in the approach procedure to detect a false glide slope. To avoid capturing a false glide slope, ILS approach procedures are designed to let aircraft capture the glide slope from below the glide slope angle.

Marker beacons provide distance measurement relative to the runway. For ILS approaches, the marker beacons provide the means to crosscheck the aircraft's glide slope to an actual point in space. The outer marker is typically about 5 miles from the runway threshold. The altitude at which a vertical line from the outer marker intersects the ILS glide slope is referenced on the instrument approach procedures charts (pilots refer to them as approach plates). Thus, if the aircraft is aligned with the ILS glide slope, it should cross the outer marker at the specified approach chart altitude. The beacon receiver onboard the aircraft flashes when the aircraft passes directly over the marker and a tone can also be heard in the cockpit if the flight crew selects this option. The middle marker is usually about 3,000 ft from the threshold. If the aircraft is aligned with the glide slope, crossing the middle marker occurs simultaneously with crossing the 200 ft above ground level (AGL) *decision height*. For Category I approaches, the decision to continue with the descent or execute a missed approach is made at or prior to reaching decision height.

4.2.2 ILS Category I Approach

As mentioned earlier, the approach phase of flight is typically done in three segments. For an ILS approach, these segments can be described as:

Segment	**Begins with:**	**Ends with:**
Initial approach	Transition from Standard Terminal Arrival Route via ATC clearance for altitude, heading, and speed	Localizer intercept
Intermediate approach	Localizer intercept	Final approach fix
Final approach	Final approach fix	Flare prior to landing, or execution of missed approach at or before decision height

The initial approach segment begins when ATC issues a clearance to transition the aircraft from a Standard Terminal Arrival Route (STAR) (or other structured airway route) to the localizer intercept, as depicted in Figure 2. The flight path to the localizer intercept is typically done with a single ATC clearance for altitude, heading, and possibly speed. However, when the controller must slow multiple aircraft for spacing and sequencing, or when the instrument approach procedure requires it, this segment may necessitate multiple clearances (for any combination of altitude, heading, and speed) for each aircraft. In any case, the last of the clearances in this segment will place the aircraft on a heading and altitude to intercept the localizer signal. To simplify the scope of this work, the assumption is made that this segment will involve a single clearance to put the aircraft on an intercept path with the localizer.

Once the aircraft has intersected the localizer, the intermediate approach segment begins. The aircraft turns to the localizer heading. The aircraft descends and maintains the altitude as specified by the approach plates. This altitude is often referred to as the glide slope intercept altitude (GSIA). However, if ATC directs an altitude that differs from the altitude specified on the approach plate, then the ATC-directed altitude always take priority over the altitude from the approach plate. Indeed, this holds true for all discrepancies between information provided by ATC directives vs. approach plates.

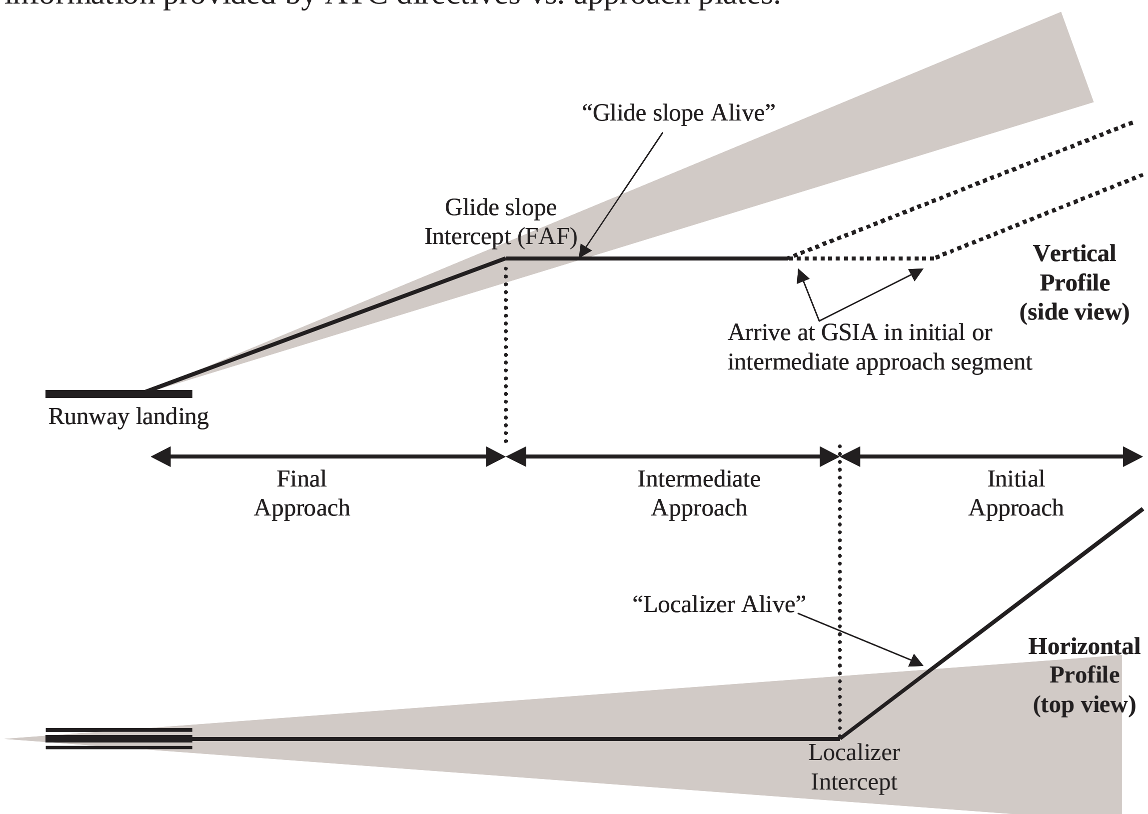


Figure 2. Segments of the ILS approach

The intermediate approach segment ends and the final approach segment begins when the aircraft descends below the charted GSIA on the ILS or when the aircraft intercepts the glide slope at an altitude below the charted GSIA.. For ILS approaches, the final approach fix (FAF) is defined in one of two ways (FAA Glossary, 2002):

1. For a glide slope intercept altitude identical to that on an approach chart, the FAF is the point that corresponds to the lightning bolt symbol on the approach chart.
2. When ATC directs a higher- or lower-than-published GSIA, it is the resultant actual point of the glide slope intercept.

Thus, for the 2nd case, the Final Approach Segment does not always begin at the same point in space, but is dependent on the ATC-directed altitude from the intermediate approach segment.

During final approach, the aircraft descends along the ILS glide slope while maintaining alignment with the runway centerline via the localizer. At 200 ft AGL, the pilot must be able to see the runway threshold to proceed with the descent and landing. However, for some carriers, seeing some part of the approach lighting system, which extend 2400-3000 ft before the threshold, will allow the pilot to continue the descent for an addition 100ft in order to attempt to see the runway. If the pilot cannot see the runway threshold, or for any reason the pilot believes it is unsafe to land, the pilot must execute a missed approach.

4.2.3 RNAV Approach
From a distance, an observer might not be able to see any difference between the flight paths followed by an aircraft using an RNAV approach versus an ILS approach. Both types of approaches use different waypoints to separate sections of the approach and both use predetermined decision heights or altitudes to define the point at which the pilots will decide to continue the approach to a landing or go-around. The main difference is that the RNAV approach does not use localizer or glideslope information projected from the runway area. Instead, an RNAV approach is based entirely on the aircraft’s internal systems and is, for the most part, simply a continuation of the process used during the descent phase. The flight path programmed into the FMC is used to maintain the approach profile down to the point of the decision altitude. Based on the distance and elevation differences between the preprogrammed waypoints, the FMC will calculate the necessary angle of descent from the Final Approach Fix (FAF) waypoint to decision altitude. The onboard navigation systems provide direction and/or control inputs designed to keep the aircraft along the correct descent path both vertically and laterally.

There are two additional differences between ILS and RNAV approaches that are important to this analysis. The first is that the ILS equipment that projects and receives the signals from the runway is more accurate than the RNAV systems. As such, RNAV approaches are limited to a higher decision altitude than are ILS approaches and can’t be used for IMC conditions with cloud decks as low as those supported by ILS.

The second difference relates to the tasks of the crew and the different automated flight modes used for the two approach types. During an ILS approach, the aircraft will continue down the glideslope beyond the decision height and potentially into the ground unless the pilots initiate a missed approach or perform a landing. During an RNAV approach, the systems are designed to automatically initiate a missed approach at the decision altitude if the pilots do not take manual control. In addition, there are a number of cue and control differences required for the RNAV approach. The specifics of how the flight crew and the aircraft systems combine to perform the RNAV approach are the main focus of this document and are described in sections 4.6 and 5.

4.3 Landing Phase of Flight

Assuming visibility permits the approach to continue, the landing phase of flight goes relatively quickly. After passing through decision height, the pilot is using visual cues to align with the runway centerline. The landing of the aircraft is very much a skill-based task.

4.4 Manual vs. Automated Control

The B757 design allows the pilot to choose the level of automation for guidance and control. In this section, three levels of automation to *control* the aircraft are discussed (guidance is discussed in Section 4.4). The three levels are the flight director, autopilot, and autothrottle:

Flight director

One type of automation is the flight director system. The flight director system does not control the aircraft per se, but rather is a decision aid that provides a visual representation on the primary flight display (PFD) of how the pilot should pitch and/or roll the aircraft to respond to guidance commands. The visual representation is dependent on customer preferences, but is typically in the form of two lines referred to as command bars (discussed in detail in Section 4.4 and depicted in Figure 6). Collectively, the two command bars on the PFD are referred to as the *flight director*. The utility of the flight director can be understood by an example. During an ILS approach, the flight director is positioned and continuously updated on the PFD to effectively guide the aircraft for alignment with the ILS signal. If the pilot can align the attitude of the aircraft with the flight director command bars, then the aircraft will align with the localizer and glide slope.

Analogous to the flight director, but used for engine thrust, the green *cursors* (also called bugs) on the display of the engine indicators depict how the pilot should manipulate the thrust to respond to guidance commands.

Autopilot

The *autopilot* controls pitch and roll by manipulating the aircraft's elevators and ailerons, respectively, in response to guidance commands. (Note that the B757 is yaw stabilized so turning the aircraft requires only a roll angle. Yaw can be controlled by manipulating the rudder via foot pedals, but this is typically only necessary during landing when the aircraft is subject to high crosswinds.)

Autothrottle

The *autothrottle* manipulates the thrust of both engines in response to guidance commands. During approach, pilots typically keep the autothrottle engaged (active) to maintain desired speed until just prior to touchdown.

Based on the SME interviews, the most common way pilots use the flight director, autopilot, and autothrottle during an instrument approach and landing are as follows:

- Full automatic control – flight director **on**, autothrottle **on,** autopilot **on**. Pilots typically use this level of automation through both the initial and intermediate approach segments, ending at either the beginning of final approach (i.e., point of glide slope intercept) or sometimes part of the way down the glide slope depending on VMC or IMC conditions.

- Flight director **on**, autothrottle **on**, autopilot **off** – Pitch and roll is controlled by the pilot's manipulation of the control yoke to follow the flight director command bars on the PFD. Pilots typically use this level of automation during the final approach if the pilot is flying in VMC, but pilot preference really dictates when the transition is made. He/she will crosscheck the flight director with what he/she sees out the window with respect to the runway centerline and VASI lights.

- Flight director **on**, autothrottle **off**, autopilot **off** – Like the previous case, but the pilot must also manipulate the thrust levers to control speed. Pilots typically use this level of automation during the end of the final approach and during landing. Although the flight director is still on, the pilot is often getting cues for lateral and glide slope alignment based on the runway centerline and VASI lights, respectively, rather than the flight director.

4.5 Flight Deck Controls, Instrumentation, and Displays

The B757 flight deck is referred to as a glass cockpit because a computer and CRT display are utilized to represent the traditional instrumentation (e.g., attitude indicator) found in older aircraft. In addition, a glass cockpit allows the functions of several different instruments to be presented on a single display, saving panel space and allowing the pilot to gather the most critical cues for a given task from one display.

The www.meriweather.com website has images of all instruments and displays on the B767 flight deck. Fortunately, Boeing designed the flight decks of the B757 and B767 to be nearly identical. The shared flight deck design feature has many advantages, one being it enables pilots to earn a common pilot type rating for both aircraft. In addition, it means the B767 information on the meriweather website is directly applicable to goals of this B757 research. The meriweather website features a Javascript capability that allows the user to "mouse over" a feature on the instrument display to learn more about it. Because of this capability and the desire to not reinvent the wheel, only a brief overview of the flight deck is presented in this document with an emphasis on depicting the primary controls, instrumentation, and displays needed during the approach and landing phases of flight. An assumption is made that if modelers have a need for more information about the flight deck, they will use the website capability to familiarize themselves as needed.

Figure 3 and Figure 4 depict an overview of the B757/767 flight deck and center instrument panel, respectively. The primary flight deck equipment that will be discussed in this section include the following:

- Flight management system
- Mode Control Panel
    - Guidance Functions
- Primary Flight Display
- Navigation Display

4.5.1 Flight Management System

The function of the flight management computer (FMC) is to assist the pilot with the planning and execution of the flight route. During the flight planning phase of flight (see Figure 1), the pilot enters flight route, aircraft, and expected conditions information into the FMC via the control display unit (CDU) interface (Casner, 2001). Collectively, the FMC and CDU are referred to as the **flight management system** (FMS). Information about the flight route includes *expected* departure runway and departure procedure, cruise altitude, arrival and approach procedures, and runway assignment. That said, the actual flight route can always differ depending on weather and ATC requirements, often requiring the pilot to reprogram the FMC in flight. The FMC is capable of calculating the optimal flight path and economical speeds during the climb, cruise, and descent phases of flight. When an aircraft is following the flight route in the FMC, it is often simply referred to as the *FMS trajectory*.

Although the FMS trajectory theoretically can be followed from takeoff to just prior to landing, the reality is that ATC clearances during the descent and approach phase of flight often differ from what has been programmed into the FMC. Pilot reprogramming of the FMC to account for ATC clearances just prior to or during the approach is not typically performed for two reasons. First, reprogramming requires long task time, cognitive workload, and heads down time (Degani et al, 1995). Second, ATC clearances just prior to or during the approach do *not* typically require aircraft conformance to crossing restrictions (i.e., crossing a navigation fix at a certain altitude and speed). Instead, ATC clearances in this phase of flight instruct the aircraft to change heading, altitude, and speed (or any combination of the three). Hence, sophisticated guidance functions (e.g., V NAV (for vertical navigation) that are needed to follow an FMS trajectory during the climb, cruise, and descent, are not typically needed, and therefore, not engaged during the approach. However, in the less commonly used RNAV approach, these guidance functions continue to be used into the approach phase.

Figure 3. B757/767 flight deck

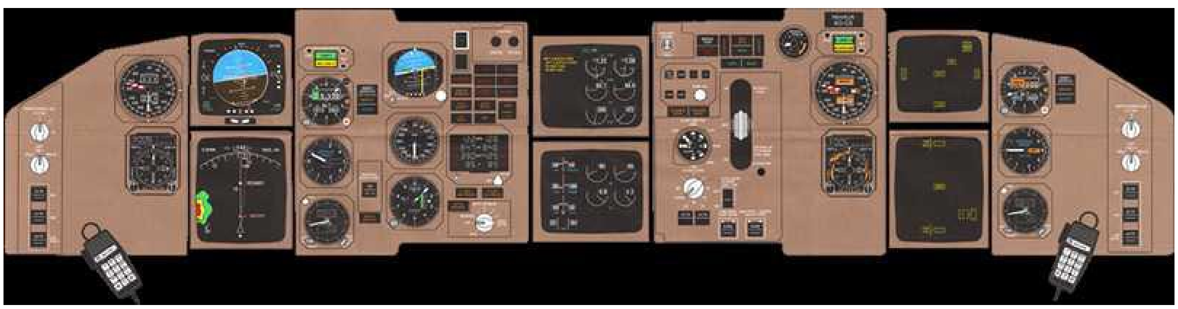


Figure 4. B757/767center instrument panel

4.5.2 Mode Control Panel

The mode control panel (MCP) is used by the pilot to select the guidance function to change the trajectory as needed. Table 1 gives an overview of these functions (adapted from Casner, 2001). The MCP allows guidance functions to be either engaged or armed. A guidance function that is engaged means that the guidance function is currently active. A guidance function that is armed means that the guidance function will engage (i.e., become active) when the required conditions for its engagement have been met. Because the guidance functions that are engaged or armed on the MCP can be difficult to decipher based on a quick glance of the MCP, a separate display, the PFD, clearly displays the roll, pitch, and thrust channels of the guidance function through what is referred to as *flight mode annunciation* (FMA). (This is discussed in more detail in Section 4.4.3)

As can be seen in the Table 1, the HEADING SELECT, ALTITUDE HOLD, and SPEED guidance functions are each dependent on only a single state – roll, pitch, and thrust, respectively. The commands for HEADING SELECT and SPEED come directly from pilot entry into the MCP. For example, if HEADING SELECT is engaged, the aircraft will begin to turn as soon as the pilot changes the heading value in the "HDG" window on the MCP (see Figure 5).

The command for ALTITUDE HOLD comes from two possible sources. In the first case, by pressing the "HOLD" button under the "ALT" window on the MCP, the aircraft will hold the current altitude indefinitely. In the second case, the altitude entered in the "ALT" window on the MCP becomes the target altitude. However, in the latter case, in order for the aircraft to change to the target altitude, FLIGHT LEVEL CHANGE must first be engaged. When FLIGHT LEVEL CHANGE is engaged, the ALTITUDE HOLD function is said to be *armed*. In this case, when the aircraft descends and reaches the target altitude, the armed condition is met and the guidance function disengages FLIGHT LEVEL CHANGE and engages ALTITUDE HOLD. In addition, the engaged pitch FMA on the PFD switches from "FLCH SPD" to "ALT" and the engaged thrust FMA on the PFD switches from "HOLD" to "SPD". (Note that the terms *flight level* and *altitude* are used interchangeably in this context).

Another guidance function that is armed prior to being engaged is APPROACH. As an example, consider an aircraft flying with constant heading, altitude, and speed via HEADING SELECT, ALTITUDE HOLD, and SPEED functions. If APPROACH is armed, it becomes engaged when the aircraft intercepts the localizer (assuming, of course, it is on an intercept course to begin with). The engaged roll FMA switches from "HDG SEL" to "LOC". At this point, the aircraft is commanded to fly the heading corresponding to the localizer signal. A short period of time later, the aircraft intercepts the glide slope and the engaged pitch FMA switches from "ALT" to "G S", corresponding to aircraft commands to fly the glide slope. The thrust FMA remains unchanged, displaying "SPD".

Table 1. B757 guidance functions for approach phase of flight

Guidance Function	How it works	FMA on PFD (see Figure 6)		
		Roll	Pitch	Thrust
HEADING SELECT	Roll used to maintain heading dialed into "HDG" window on MCP. 1) Dial new heading	HDG SEL		
ALTITUDE HOLD*	Pitch used to maintain present altitude. 1) Push altitude "HOLD" button to maintain present altitude		ALT	
SPEED	Adjustments to thrust used to maintain speed dialed into "IAS/MACH" window on MCP. 1) Dial new speed 2) Push "SPD" button			SPD
LOCALIZER*	Rolled used to track dialed localizer. 1) Dial ILS course and frequency on ILS panel. 2) Arm function by pushing "LOC" button. 3) Function captures localizer.	LOC		
APPROACH* (localizer + glide slope)	Roll used to track dialed localizer. Pitch used to maintain dialed glide slope. Adjustments to thrust used to maintain speed dialed into "IAS/MACH" window on MCP. 1) Dial ILS course and frequency on ILS panel. 2) Dial new speed (if needed). 3) Arm function by pushing "APP" button. 4) Function captures localizer or glide slope.	LOC	G S	SPD
FLIGHT LEVEL CHANGE	Thrust of engines set to idle. Pitch used to maintain speed dialed into "IAS/MACH" window on MCP. 1) Dial new altitude 2) Dial new speed (if needed) 3) Push "FL CH" button 4) Descends to new altitude and then switches to ALTITUDE HOLD.		FLCH SPD	HOLD

* Guidance functions that can be armed prior to engagement

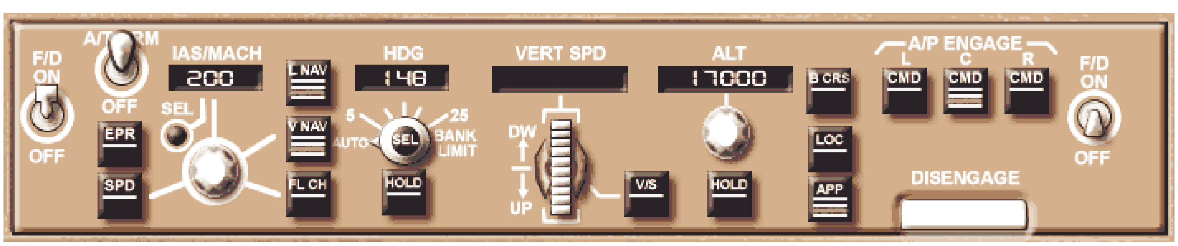


Figure 5. B757/767 Mode Control Panel

MCP description

A brief description of the MCP panel for functions used during approach is presented. Functions used in other phases of flight are not discussed here to keep it simple.

F/D – flight director for captain (far left) and first officer (FO) (far right)
ON – Allows display of Flight Director command bars on respective PFD.
OFF – Removes Flight Director from respective PFD.

A/T ARM
ARM – Arms auto throttle for engagement.
OFF – Disarms autothrottle, preventing engagement.

IAS/MACH – Speed indicator.
Speed Knob – Changes the value in the speed indicator.
SPD – Engages SPEED function.
FL CH – Engages FLIGHT LEVEL CHANGE function.

HDG – Magnetic heading indicator.
SEL Knobs – Inner knob – Changes value in heading indicator.
Outer knob – Bank limit selector .
Heading HOLD – engages HEADING HOLD(not listed in Table 1).

ALT – Altitude indicator.
Altitude Knob – Changes the value in the altitude indicator. Turning the dial slowly translates to 100 foot increments within the display. Turning the dial more quickly results in 1000 foot increments within the display.
Altitude HOLD – Engages ALTITUDE HOLD mode manually.

LOC – Arms or engages LOCALIZER to intercept and track localizer.

APP – Arms or engages APPROACH to intercept and track both localizer and glide slope.

CMD – Engage associated autopilot in vertical speed and heading hold modes if neither flight director is on, or if either flight director is in the takeoff or go-around mode.

Disengage Bar
Up position – Allows autopilots to be engaged.
Down position – Disconnects all three autopilots from flight control servos preventing engagement of autopilots.

Figure 6. B757/767 Primary Flight Display

4.5.3 Primary Flight Display

During the approach, the PFD (also referred to as Attitude Director Indicator (ADI)) is the primary navigation instrument. Both captain and FO have a PFD. The information provided by the PFD is as follows:

Center of display

- Artificial horizon depicted by blue/black
- Transparent “aircraft wings” (outlined in white) depict current attitude of aircraft in terms of pitch and roll
- “Red cross” depicts the Flight Director (FD) command bars, which shows pitch and roll commands generated by the FMC. Typically, the autopilot or pilot rolls and pitches the aircraft to align the “aircraft wings” with the FD.

Upper left corner

- GS200 – Ground speed in knots (200 knots in this example)

Upper right corner

- DH150 – Decision height in ft entered by pilot (150 ft in this example)
- 1750 – Altitude in ft AGL provided by radio altimeter (1750 ft in this example). Note that radio altimeter makes use of the reflection of radio waves from the ground to determine the height of the aircraft above the surface.

Note: For next two groupings, words/abbreviations in green font indicate the associated mode is engaged (active). Words/abbreviations in white font indicate the associated mode is armed. The list and meaning of FMA is described in Table 1.

Lower left corner:

- A/T (in green) – this location on the display indicates autothrottle system status. In this example, the autothrottle is engaged.
- SPD (in green) – this location on the display indicates autothrottle FMA. In this example, SPD (for speed) is engaged.
- G S (in white) – this location on the display indicates *armed* pitch FMA. In this example, G S (for glide slope) is armed.
- V NAV (in green) – this location on the display indicates *engaged* pitch FMA. In this example, V NAV (for vertical navigation) is engaged.

Lower right corner:

- CMD (in green) – the autopilot/flight director status. In this example, CMD means autopilot is engaged. If FD is displayed instead, it means the flight director is engaged and autopilot is disengaged.
- LOC (in white) – this location on the display indicates *armed* roll FMA. In this example, LOC (for localizer) is armed.
- LNAV (in green) – this location on the display indicates *engaged* roll FMA. In this example, L NAV (for lateral navigation) is engaged.

Bottom center:
White dots and pink marker – localizer pointer and scale indicates localizer position with respect to aircraft. In this example, the pink indicator is right of center so the aircraft must turn to the right. This is also consistent with the flight director, which is commanding a turn to the right.

Center right:
White dots and pink marker –glide slope pointer and scale indicate glide slope position with respect to aircraft. In this example, the pink indicator is above the center mark so the aircraft is below the glide slope. This is also consistent with the flight director, which is commanding a pitch up. A term often used by pilots is *one dot below glide slope*. Note that this refers to pink indicator pointing at the first white dot *above* the center mark, but the aircraft is actually *below* the glideslope. Pilots use this indicator to configure the aircraft for the final approach. Glide slope intercept occurs shortly after.

Center left:
White dots and pink marker – fast/slow indicator depicts deviation from airspeed selected manually with the IAS/MACH selector or calculated automatically by the FMC when in V NAV. In this example, because indicator is centered, no adjustment in speed is needed.

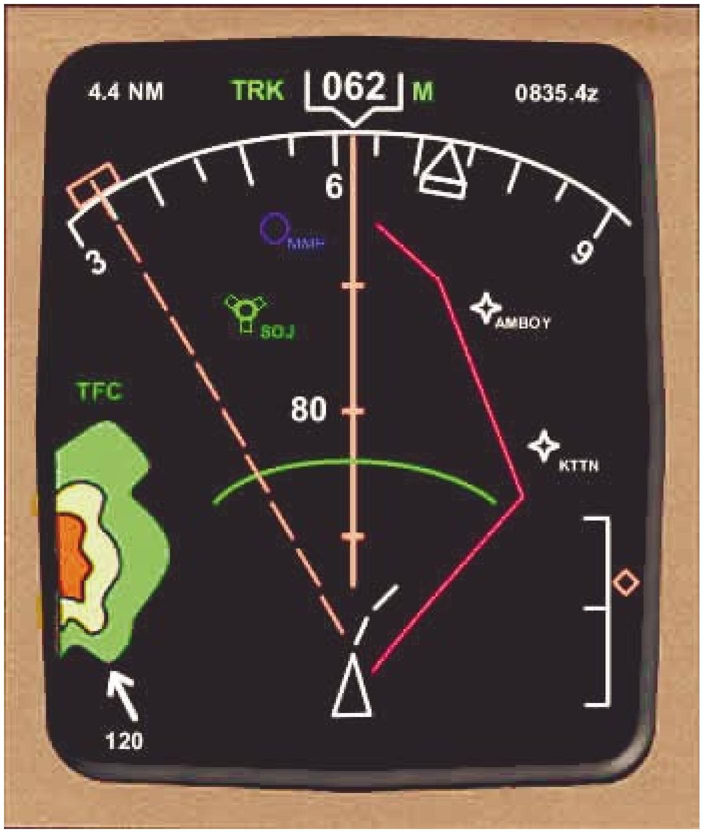


Figure 7. B757/767 Navigation Display in Map mode

4.5.4 Navigation Display

The navigation display (ND), also called the horizontal situation indicator (HSI) or LNAV display, provides a map view (see Figure 7) of the area in which the aircraft is headed. Both captain and FO have a ND. The ND can be configured in various modes that can show all the planned waypoints from beginning to end or more detailed displays for any section of the flight.

ND display description

Bottom center

- White triangle – aircraft symbol. Apex of triangle indicates aircraft position relative to display.
- White dashed line – curve trend vector. Indicates predicted airplane track in 30, 60 and 90 second intervals when turning.

Center display

- “AMBOY” and “KTTN” with waypoint symbols – indicate waypoints. White for inactive, magenta for active.
- “SOJ” with VORTAC symbol – indicates VORTAC navigation aid. When NAVAID switch is ON, all appropriate navigation aids in range appear in addition to those navigation aids which are standard or active.

- "MMP" with blue circle – indicates airport. When the ARPT switch is ON, displays airports within the map area.
- "80" – Range from aircraft to associated tic. 80 nm in this example. Also indicates half of the range selected on the ND range selector. In this example, the ND range selector is set to 160 nm, displaying a moving map 160 nm in front of the aircraft.
- Magenta solid line – indicates flight plan route line.
- Pink solid line with tic marks – indicates track line based on prediction of track for present heading and wind.
- Pink dashed line – indicates the selected heading as set in the MCP. In this example, the heading is set to 35 degrees.
- Green arc – indicates altitude arc. The intersection of the green arc with either the track line or flight plan route represents the point where the aircraft will be at the altitude set in the MCP altitude indicator.

Upper left corner

- 4.4 NM – indicates distance to next waypoint in MAP or PLAN modes. 4.4 nm in this example.

Upper center

- TRK 062 M – magnetic track/heading display. 62 degrees in this example. The true heading is displayed by a white triangular pointer along the compass. In this example, the true heading is 73 degrees.

Upper right corner

- 0835.4z – indicates ETA to next waypoint in Zulu time.

Bottom right corner

- White line and tics with pink diamond – the vertical deviation indicator, which depicts the altitude deviation from the selected vertical profile.

Bottom left corner

- White arrow and "120" – the wind display. Indicates wind direction relative to map display orientation and speed (in knots). In this example, the aircraft is experiencing a 120 knot tail/side wind.
- Multicolored display – weather radar returns. Returns are presented when WXR ON switch is pushed. Highest intensity is displayed in red, lesser intensity in amber, and least intense in green. Turbulence is displayed in magenta.

Center left corner

- TFC – indicates TFC button is selected ON, which means the TCAS Traffic Display is active.

4.5.5 Traffic Alert and Collision Avoidance System

The traffic alert and collision avoidance system (TCAS) is an airborne collision avoidance system based on radar beacon signals which operates independent of ground-based equipment. TCAS generates traffic advisories, and resolution (collision avoidance) advisories in the vertical plane. TCAS is a backup system to ATC, which is the primary system for keeping aircraft safely separated.

4.6 LNAV / VNAV Flight Modes in RNAV Approach

The aircraft uses two guidance systems combined with the autopilot and autothrottle to maintain the flight path programmed into the FMC. The lateral navigation (LNAV) guidance function directs the roll of the aircraft while the vertical navigation (VNAV) guidance function directs the pitch and thrust of the aircraft to guide the aircraft between the waypoints. When the VNAV mode is engaged and the aircraft is following the vertical path programmed into the FMC, the aircraft is in the VNAV PATH mode. During the descent, the pilots must interact with this system to maintain the VNAV PATH mode. Although the FMS is controlling the aircraft based on the goal of reaching the active waypoint, it will not automatically make a change to the target altitude when reaching the waypoint during a descent. Instead, the pilots must set the next desired altitude into the MCP before reaching the active waypoint. If a new altitude is not set, the aircraft will establish level flight at it’s current altitude and drop out of the VNAV PATH flight mode.

During most of the descent and approach, the process involves setting an altitude lower than that of the aircraft. When a new altitude is set, the aircraft will maintain it’s current altitude or current descent profile until the next waypoint is reached provided VNAV PATH is maintained. From there it will begin a new descent from the current waypoint position to the next active waypoint based on the new altitude that was set in the MCP. However, during the descent from the last waypoint (often the FAF) to the decision altitude, the pilots must set a missed approach altitude that is often higher than the current altitude of the aircraft. While setting the missed approach altitude in the MCP, it is possible for the aircraft systems to ‘capture’ an altitude. If this occurs, the aircraft will drop out of VNAV PATH into altitude capture and perhaps into altitude hold and transition to level flight at the captured altitude. In order to prevent altitude capture in this situation, the pilots must spin the altitude setting dial quickly (see MCP controls description in section 4.5.2) usually beyond the missed approach altitude then turning the dial more slowly back to the desired setting.

5 Approach/Landing Tasks and Events

This section discusses the tasks of the approach and landing phases of flight for the B757. The material has been obtained from flight manuals, other reports and pilot interviews. Although the information is focused on the 757 and an RNAV-type approach, it is not specific to any airport or airline. The approach scenario used in the task analysis was based on the FMS RNAV approach to runway 29 at the Oakland International Airport in Oakland, CA. When necessary, the task analysis uses specific data from this approach and identifies it using parentheses (). The idea is that the modeling teams will be able to use the specific information when needed but can substitute details from another approach, such as the one used in the simulator experiments, if they choose. Where applicable we have noted important task related differences associated with different airlines and different airports. The specific information presented in this section covers the following:

- An overview of the tasks required for RNAV approach and landing (Section 5.1)

- Detailed descriptions of each task including a task table and event time-line (Section 5.2)
- Review of the RNAV approach plate used in the simulator experiments (Section 5.3)
- Description of some of the problems and errors associated with flying the approach and landing phases of flight (Section 5.4)

5.1 Overview of Tasks

This task analysis is focused on the approach phase of flight. Following the cruise phase, the crew will transition from the flight corridors to the approach area for a specific airport. The approach is essentially the portion of the flight in which the crew establishes the aircraft in the appropriate location, attitude and position to land. For both manual and automated flight, this involves incrementally slowing to landing speeds, descending to appropriate altitudes for landing and aligning the aircraft with the runway such that the landing can be executed within the appropriate runway confines. The maneuvers performed by the crew for both the approach and landing must be within the limitations of the aircraft, the procedures of the airline, the requirements of ATC, while supporting the safety and comfort of the passengers.

During the approach, the crew will make a series of speed and wing flap adjustments in order to maintain the necessary descent rate of about 300ft/mile (3 degrees) and to slow the aircraft. The minimum flap settings are a function of the weight and speed of the B757 whereas the maximum flap settings are a function of only the speed. The minimum flap setting provides the additional lift needed to keep the aircraft maneuverable at slower speeds. The maximum flap setting prevents the flaps from being damaged due to deployment at excessive speeds. Representative flap settings are given in the task table in Section 5.2.2.

The crew will also be configuring the systems for an RNAV approach. The configurations enable the aircraft's internal systems to maintain the preprogrammed approach path until the pilots are able to see the runway and perform a manual landing. The SME indicated that the goal of the crew during an RNAV approach would be to have the aircraft fully configured prior to beginning the final descent before the decision altitude. In addition, the crew will be interacting with ATC as needed to get appropriate elevation, approach and landing clearances and other information and instructions. The crew will also be monitoring the systems, the progression of the flight plan, and the attitude and flight path of the aircraft. The tasks are shared (usually by established procedure) between the Pilot Flying (PF) and the Pilot Not Flying (PNF). The primary tasks of the PF involve all aspects of the aircraft attitude, position and function. The PNF will perform necessary communications, respond to requests from the PF, and double check actions of the PF. Usually, tasks of monitoring the flight control displays and 'looking outside' are also distributed based on visibility and distance form the airport.

For the purposes of this task analysis, we made several basic assumptions about the aircraft and set several initial conditions for the beginning of the approach phase tasks. The following are the assumptions and initial conditions of the aircraft and flight, and a brief narrative of the approach and landing task sequence. The aircraft, passengers and baggage weigh 180,000 lbs and the associated speed and flap settings are listed with the task table. The aircraft has finished the descent phase of flight and is transitioning into the approach phase. The flight is proceeding under IMC rules using an RNAV approach procedure. The aircraft is approximately 15 miles from the runway threshold flying level at 2500 ft AGL at 200 kts with flaps set at 5 degrees. The approach is programmed into the FMC. Both the autopilot and autothrottle are engaged and the Flight Mode Annunciators (FMA) indicate the LNAV and VNAV PATH modes. The MCP altitude is set to 2500ft and the necessary radio frequencies have been set. The tasks begin as they receive approach clearance.

Upon receiving the approach clearance from approach control and instructions to slow to 160 kts, the crew verifies LNAV and VNAV PATH, sets the speed and sets the flaps to 15. Once the settings have taken affect, they deploy the landing gear, reduce speed again and set the flaps to 20. At about 150 kts, they set flaps 25. Very shortly after this, they set flaps 30 (the final flap setting) and perform the before landing checklist. One or two miles before reaching the FAF, the crew sets the DA and again verified LNAV and VNAV PATH modes. Once they have begun to descend after the FAF, they set the missed approach altitude. Upon crossing the outer marker at five miles from the runway threshold, the crew makes their final approach preparations, changes their communication radios to the tower frequency and requests a landing clearance. About 100 feet above the DA, the crew makes their final landing determination. If they cannot see the runway, they will let the aircraft initiate a go-around. If they can see the runway, then the landing continues. If the runway is in site before the decision altitude is reached, the PF will often switch to manual flying prior to decision altitude. The point at which the crew begins to manually fly the aircraft varies with the crew but is usually associated with the ability to see the runway.

5.2 Event Timeline and Task Analysis

This section includes detailed descriptions of each task included in the event and task table. The descriptions are specific to approach and landing and the B757. They are not intended to represent similar tasks from other phases of flight or other aircraft.

5.2.1 Task Descriptions

<u>Voice communication to ATC</u>
When the crew communicates with ATC, it is either initiated by the crew or in response to communication from ATC. Contact initiated by the crew usually takes the form of an identification call and/or request for clearance or information. Responses usually involve reading back ATC instruction or providing requested information. Voice communication requires the crewmember to press one of the mic buttons on the yoke or on the center console and speak into their headset microphone.

<u>Switching Radio Frequencies</u>
The two VHF Communications control panels on the horizontal panel between the two crew members allow for two communication radio frequencies to be dialed in. A toggle switch on the panel allows the crew to switch from one preset frequency to another. During the approach, the crew will be using the approach control frequency. At or near the outer

marker, the switch will be flipped to the other preset frequency which they crew would have set to the tower frequency for the airport.

Double Checks and Verifications

Throughout the approach and landing process both crewmembers are checking and double-checking the accuracy of settings that include altitude, speed and flaps. Sometimes these checks require consulting a reference such as the speed versus flaps settings based on the weight of the aircraft. Other times the same steps are done so frequently that the crew has expectations of what the settings will be. In these cases double-checks can be characterized as a mental process of determining if an expectation has been violated. For example, if the PNF is expecting a particular flap setting and the PF asks for a different one, the PNF would detect the difference from the expectation rather than looking up the value to see if it was correct.

Verifying LNAV/VNAV PATH

Verifying that the aircraft systems are in LNAV and VNAV PATH involves looking at the flight mode annunciators on the Primary Flight Display (Figure 6). The letters 'LNAV' will show in green in the lower right corner if in the LNAV mode and 'VNAV PATH' will show in green in the lower left corner if in the VNAV PATH mode. In addition, the crew will verify that the decision altitude waypoint and altitude and missed approach path are correctly programmed into the FMS. The planned waypoints and altitudes are shown on the HSI.

Checking position along flight path

The HSI shows the position of the aircraft relative to the flight path programmed into the FMC. This includes the current heading, wind speed and direction, waypoints and distance to the active waypoint.

Checking the Airspeed and Bug settings

Checking the airspeed requires looking at one of the two air speed indicators. The indicators include markers along the outside of the dial called bugs that are set to reference specific speeds during flight preparation or prior to descent when planning the descent and approach phases. The bug settings on the dial will let the crew know the relationship between speed and flap settings relative to the weight of the AC. The pilot flying will often ask for a speed setting relative to a bug position.

Set speed on the Mode Control Panel

Either pilot may change the speed setting on the MCP. When the autothrottle are engaged, the aircraft will attempt to maneuver to attain the new speed. Setting the speed requires turning the speed mode dial until the desired speed is indicated by the digital display above the dial. Verifying that the correct speed has been entered requires looking at this display.

Flaps

The flaps may be set by either pilot but is easier from the right side seat since the flap lever is positioned to the right of the throttle controls. When used from the left seat, it requires a slightly higher level of dexterity to reach around the throttles and the flap lever position is more difficult to determine. Setting the flaps requires using one hand to move the flaps lever to the correct position and requires the operator to look at the position labels. The lever will click into a position detent for each setting. Each position is labeled. During approach and landing, the lever is periodically moved downward to the next appropriate position. Usually the PNF will set the flaps based on a flaps request from the PF. The PNF will verbally respond to the PF with the flaps setting at the same time he uses the lever to adjust the setting. Verifying the position of the flaps requires looking at the panel just to the right of the flaps lever to see which label corresponds with the location of the flaps lever. They may also use a hand to check if the lever is settled into the current position detent.

<u>Monitoring Speed and Flaps changes</u>

During a change in speed and/or new flaps setting, both crewmembers perform specific monitoring tasks to determine if the changes are taking the desired affect on the aircraft attitude. The PF can hear the flaps lever click into the detent for the new position. Although he will not know without looking which setting has been selected, he will know when the flaps will begin to deploy. As they deploy, both pilots can feel the change in the pitch of the aircraft and see the stall indicator change on the PFD as the pitch changes. They will both also watch the air speed indicator to determine that the air speed is changing as intended. The maneuver of slowing and setting flaps to 15 is usually consistent with attempting to intercept the glide slope. In addition to monitoring the pitch and speed change, the crew will be watching to see the glide slope indicator on the PFD (Figure 6) announce that the aircraft is beginning to intercept the glide slope referred to as ‘glide slope alive’. Following the maneuver of continuing to slow and setting flaps 30, the crew will monitor the glide slope indicator on the PFD waiting for it to indicate that the glide slope has been captured.

<u>Landing Gear</u>

Lowering the landing gear requires moving the landing gear lever all the way down (‘down’ for down). The lever is closer to the right seat and requires only one hand to push the lever down. If done from the left seat, it may require leaning the upper body to reach the lever. Verifying that the gear is down requires looking at the three indicator lights above the landing gear lever. They are positioned in a triangle (nose, left and right rear). If all three are green, then the landing gear is down.

<u>Speed Brake</u>

The speed brakes are controlled using a lever on the left side of the throttles. The lever is moved back (aft) to put out the speed brakes (or spoilers) on the wing that will ‘spoil’ the lift of the wing and allow the aircraft to descend faster. The speed brakes also work automatically upon touchdown of all landing gear to slow the aircraft. In the forward position, the lever is in a detent indicating that the brakes are stowed. The next setting is the ‘armed’ position used for automatic deployment during landing. Beyond that, the lever can be moved farther back to vary the amount the spoiler panels are deployed. Verifying that the speed brakes are armed requires looking to determine that the lever position corresponds with the ‘armed’ label on the panel next to the lever. Verifying that the speed brakes are stowed requires looking to determine that the lever is in the forward position and using one hand to feel that it is in the detent.

Set Altitude on the Mode Control Panel

Setting the altitude requires using the altitude knob on the Mode Control Panel to dial the desired altitude. The altitude setting is displayed above the dial. The missed approach altitude is defined as the altitude to climb to in the event of a missed approach. The altitude is read off the approach plate while reviewing the approach procedure during the descent phase of the flight. Setting the missed approach altitude during an RNAV approach while in VNAV PATH requires spinning the dial fast enough (see MCP controls description in section 4.5.2) to prevent the aircraft systems from capturing the new altitude and dropping out of the VNAV PATH mode. When this is done, the pilots will have verified that LNAV and VNAV PATH remain active and that the aircraft is tracking on the vertical profile as depicted on the HSI prior to resetting the MCP to the missed approach altitude.

Monitoring Altitude below 2500 ft

The display for the radio altimeter is on the PFD and is collocated with the decision height display. When altitude callouts are required below 2500 ft the crewmember making the callout will look at the radio altimeter display. This also allows the crewmember to determine how far they are from decision height/altitude. The altitude based callouts (1000ft, 500ft etc) are all given as AFE (Above Field Elevation) rather than AGL (Above Ground Level). This is because the PF wants to know how far below him the runway is. However, the radio altimeter is showing how far the ground is below the aircraft and some runways are at the base of hills on raised above the surrounding terrain. In such situations, the PNF may have to make a mental calculations to determine AFE based on the radio altimeter readings of AGL.

Landing Checklist

The landing checklist is a sequence of four checks that are executed by the PNF designed to verify certain critical tasks have been completed. Each step is called out by the PNF and an associated check is done. Depending on the airline, the PF is not required to verbally respond to any of the checks as they are the duty of the PNF. However, the PF will usually follow along with the checks and silently verify each one as the PNF reads through the list. It seems to be the policy of most airlines that the landing checklist actually be done by reading the steps off the card rather than from memory. All the SMEs we interviewed indicated that they only use the checklist card but acknowledged that there are some pilots who do the checklist from memory.

Identification Call

When the crew switches from the approach control radio frequency to tower control they will make an identification, location and intention call to the tower. The identification will include the call sign for the flight, which usually includes the company and flight number (United 123, NASA 111, etc). The location will include a reference to a waypoint such as the final approach fix (Inbound from Alvar). The intention is expressed by telling the tower which runway they are headed for. An example call would be, “Oakland tower NASA 111 inbound from Alvar for runway 29.” The tower will usually respond with a clearance to land on the requested runway. The crew will then read back the clearance to the tower to verify their understanding of the clearance instructions.

Landing lights

The controls for the landing lights are a series of labeled switches on the middle overhead panel. Turning on a specific light or set of lights requires depressing the correct switch based on the lighting needs and associated labels.

Descent Rate

The descent rate is determined by looking at one of the two Vertical Speed Indicators which are analogue dials showing the vertical change in feet per minute.

Executing Missed Approach

In the event that the pilots determine they need to execute a missed approach the will execute several actions in quick succession in order to change the profile from an approach to a landing to a climb. The sequence involves advancing the throttles to go-around thrust, setting the flaps to 20, establishing a positive climb profile and retracting the landing gear. Some of these actions will be executed by the automatic systems if the DA is reached during an RNAV approach but the pilots will still act to execute and/or monitor these actions.

Disengage Autopilot

The PF will turn off the autopilot when he has chosen to fly the aircraft manually. Prior to doing so, he will have both feet on the rudder pedals and place his hands on the control yoke. Once his hands are on the controls, the switch to disengage the autopilot is mounted on the outboard side of either yoke and is controlled using the thumb. An alarm will sound as the autopilot is disengaged and the PF will turn off the alarm annunciator by depressing a switch on the Mode Control Panel.

Manual Flight

Once the PF has disengaged the autopilot and taken manual control of the aircraft, his attention will be evenly distributed between looking out the window and scans of the instruments. Both hands and both feet are required to perform the tasks of manual flight. The PF will be making constant minor adjustments to maintain runway alignment, heading, speed, and sink rate using the yoke controls and rudder foot pedals. This will also require moving one hand from the yoke controls to the thrust levers for minor adjustments.

Flare

The action of flaring the aircraft brings the pitch up just slightly to cause the aircraft to settle onto the main landing gear. The PF applies back pressure to the yoke until the desired pitch is reached then feels for the contact of the main landing gear.

Monitoring Flight Path and Progress

This task is periodically performed by both crewmembers throughout all phases of flight. The task primarily involves scanning the instruments to ensure that the aircraft has not deviated from the expected path, altitude, attitude and overall flight plan. Looking at the

HSI (Figure 7) allows the crew to determine if the flight path of the aircraft is along the proper heading and in accordance with the flight plan entered into the FMC. Looking at the FMA on the PFD allows the crew to determine if the aircraft is conforming to the prescribed attitude at any point during the flight and determine the configuration and functioning of the various automated flight support systems. Other displays such as the vertical speed indicator allow the crew to monitor the progress of various changes or determine that unexpected changes may be occurring.

Monitoring the Party Line

This task involves listening for communications on the frequency that is currently set. Auditory information is received through the ear piece or headphones used by the crew. The information may include specific communications from ATC directed at the crew, communications between ATC and other aircraft, or communications between aircraft. This monitoring task requires no workload when there is no communication traffic on the frequency. At such times, there is no information available to monitor. Attention is directed to the party line only when communication is initiated by the crew or when attention is drawn by communication traffic over the party line. When communication traffic does occur, the crew will quickly determine if the information is directed at them based on their call sign. They will also quickly determine if the communication is coming from ATC or another aircraft. When the communication is for the crew, they will closely attend to the information. Most communications are from ATC and involve approach and landing instructions or clearances and are expected by the crew. The crew will also monitor communications with other aircraft to the extent that they might be affected by what other aircraft are doing or how ATC is managing the airspace. ATC communications to them will either confirm their expectations of their approach and landing profile or require them to make some sort of change. Listening to communications from ATC to other aircraft or between aircraft help the crew build a mental picture of where they are in the airspace relative to the other aircraft and provide them with an idea of what to expect as they get closer to the airport. The volume of communication will vary depending on a variety of factors including volume of aircraft in the airspace and weather. At it's worst, the traffic on the party line can be continuous as ATC and flight crews initiate and respond to each other requiring some level of constant attention by the crew. At such times, it can be difficult to find a break in the flow to initiate a call and multiple callers may even try to talk over each other at the same time.

Monitoring Aircraft Systems

This task is periodically performed by both crewmembers throughout all phases of flight. The status of any of the different aircraft systems can be checked using several different cockpit displays. Checking such displays helps the crew to determine that the aircraft systems are operating with normal tolerances and can be used to determine if a system is beginning to have a problem. The system displays include alert flags and problem annunciators that will draw the attention of the crew when problems occur. As a result, the scan of these instruments in the absence of flags or alarms is infrequent.

5.2.2 Event and Task Table

The following table lists the sequence of tasks performed by the crew during the approach and landing. They are broken into sequences of tasks associated with specific events. Usually, the crew will perform a sequence of tasks in response to a location stimulus or communication. Each task execution sequence is usually followed by a period of monitoring as configuration settings take place or the crew weights for the next event initiator.

Each crew performs the tasks slightly differently. Often the callouts and double checks are occurring simultaneously with system setting tasks as each crewmember task performance overlap the other. As such, an overall time has been given for each sequence of tasks rather than providing individual timing information for each task. The table also lists the distribution of tasks between PF and PNF in the operator column. Each event is listed with a descriptive title and approximate aircraft position and remaining time to wheel-touch. Altitudes are given as distance AGL. Speeds are given in knots (kts). Task descriptions are either short statements of an action or, when in quotes, represent a spoken phrase. The tasks are also classified as discrete, intermittent or continuous based on the schedule of task performance. Discrete tasks are those that required single non-recurrent performance, such as activating or deactivating a system, making a setting, or stating a phrase. Intermittent functions are those that required multiple, recurrent performance such as periodically monitoring a display. Continuous tasks are those that require variable but uninterrupted performance, such as controlling aircraft heading or speed (McGuire 1991).

Initial Conditions

- Boeing 757
- 180,000 lbs
  - o

Speed (kts)	Min. flap settings f(weight, speed)	Max. flap settings f(speed only)
240	flaps 0	flaps 1
220	flaps 0	flaps 5
210	flaps 0	flaps 15
205	flaps 1	flaps 15
195	flaps 1	flaps 20
185	flaps 5	flaps 25
165	flaps 15	flaps 25
145	flaps 20	flaps 30
125	flaps 30	flaps 30

- Approach is FMS RNAV
- Instrument Meteorological Conditions (IMC)
- ~15 miles to runway threshold
- ~10 miles from outer marker (OM)
- 2,500 ft AGL
- Level Flight
- 200 kts
- Flaps 5
- FMA indicates LNAV / VNAV PATH

- Autothrottle and Autopilot engaged
- Approach is programmed into the FMC
- 2,500 ft is set in the MCP
- Approach and landing radio frequencies are set
- PF has hand and feet on the controls to feel feedback from the aircraft

5.2.2.1 Sequential Events and Tasks

Event / Task Description	Operator	Type
Receive Approach Clearance		
• ~2,500ft AGL • 15 miles out • The ATC communication and read back take approximately 5 seconds. • Once the read back is complete, the task sequence listed for this event takes approximately 10 seconds for the crew to complete.		
ATC Communication: “You are 10 miles from the marker, cleared for approach, slow to 160”	ATC	Discrete
Read back clearance and speed	PNF	Discrete
Check to ensure LNAV / VNAV PATH	PF	Discrete
Check airspeed	PF	Discrete
Says, “Speed 160, Flaps 15”	PF	Discrete
Sets speed to 160	PF	Discrete
Check speed setting	PNF	Discrete
Check speed against reference bugs	PF	Discrete
Mentally confirms flaps vs. speed settings	PNF	Discrete
Sets flaps 15, says “Flaps 15”	PNF	Discrete
AC Attitude Adjustment		
• Flap deployment takes about 30 to 40 seconds to complete.		
Hear flap lever go into detent	Both	Discrete
Feel pitch change	Both	Continuous
Monitoring PFD	Both	Intermittent
After Sufficient Slowing		
• ~13 miles out • The task sequence listed for this event takes approximately 10 seconds to complete.		
Says, “Gear Down, Flaps 20, Speed plus 5”	PF	Discrete
Deploys gear & says “Gear”	PNF	Discrete
Sets flaps 20 & says “Flaps 20”	PNF	Discrete
Set target speed (135)	PF	Discrete
Check speed setting	PNF	Discrete

AC Attitude Adjustment		
• Flap deployment takes between 30 and 40 seconds to complete		
Hear flap lever go into detent	Both	Discrete
Feel pitch change	Both	Continuous
Monitoring PFD	Both	Intermittent
After Further Slowing		
• As speed passes approximately 150 kts. • The task sequence associated with this event takes less than 10 seconds to complete.		
Says, “Flaps 25”	PF	Discrete
Sets flaps 25 & says “flaps 25”	PNF	Discrete
AC Attitude Adjustment		
• Flap deployment takes approximately 20 seconds to complete		
Hear flap lever go into detent	Both	Discrete
Feel pitch change	Both	Continuous
Monitoring PFD	Both	Intermittent
Final Flaps and Landing Checklist		
• As speed passes approximately 140 kts. • The task sequence associated with this event takes less than 30 seconds to complete.		
Says, “Flaps 30 and landing checklist”	PF	Discrete
Sets flaps 30 and says, “flaps 30”	PNF	Discrete
Get list or starting from memory	PNF	Discrete
“Cabin notification?”….. “Complete”	PNF	Discrete
“Gear Down?”	PNF	Discrete
Check gear lights	Both	Discrete
“Down and checked” (or “Down, three green lights”)	PNF	Discrete
“Speed brakes armed?”	PNF	Discrete
Check speed brakes (manually)	PNF	Discrete
Check speed brakes (visually)	PF	Discrete
“Armed”	PNF	Discrete
“Flaps?”	PNF	Discrete
Check flap settings	Both	Discrete
“30 planned, 30 indicated”	PNF	Discrete
“Landing checklist complete”	PNF	Discrete
Stabilization Gate		
• ~ 11 miles out (6 from the OM) • 1 to 2 miles prior to descent from (2500) ft FAF, the aircraft must be stabilized, fully configured, flaps 30 and landing checklist complete • Set next altitude in MCP prior to beginning of last descent. This can be done any time after established at (2500) ft.		

Sets decision altitude in MCP (600ft)	PF	Discrete
Verify decision altitude setting	PNF	Discrete
Verify LNAV / VNAV PATH	PF	Discrete
Crossing Final Approach Fix (FAF)		
• ~ 9 miles out		
Says name of FAF (“Alvar”)	PNF	Discrete
Says “Decision Altitude is set at (600 ft) barometric”	PF	Discrete
Feel descent	Both	Continuous
Stabilized on Descent		
• ~2,000ft • Set missed approach altitude • If altitude capture occurs while resetting to the missed approach altitude then the crew will execute a missed approach.		
Verify LNAV / VNAV PATH	PF	Discrete
Sets missed approach altitude (dial spin, 4000ft)	PF	Discrete
Monitor to determine altitude capture has not occurred	Both	Continuous
Cross Outer Marker		
• ~5 miles out • 125 kts • ~2 minutes • The time associated with this task sequence can vary depending on how long it takes for ATC to respond with the landing clearance. It should take less than 45 seconds. The call to ATC could happen anytime after starting the descent from the FAF.		
Switch to tower radio frequency	PNF	Discrete
Make id, location and intention call	PNF	Discrete
Tower responds with landing clearance	ATC	Discrete
Read back of clearance	PNF	Discrete
Set taxi light	PF	Discrete
1000 ft Call out		
• ~1,000 ft AFE (above field elevation) •		
Scan all instruments looking for error/warning flags	PNF	Discrete
if no flags, “1,000 feet, flags checked”	PNF	Discrete
Says, “Runway XX, Cleared to land”	PF	Discrete
~100 ft above DA (700 ft)		

• The pilot must make the landing determination prior to reaching the DA or the aircraft will automatically initiate a missed approach when reaching the DA due to the altitude setting in the MCP. • The point at which the PF begins hands flying the plane could have taken place before this whenever the runway is sited (see Transition from automatic to manual flying event). • If the runway is not sited by the time decision height is reached, then they will execute a missed approach.		
Says “Approaching DA”	PNF	Discrete
if runway is in site, call out runway site	PF	Discrete
Hands Fly the Landing		
Looking far down runway	PF	Intermittent
Hands flying AC	PF	Continuous
Monitor instruments	PNF	Intermittent
Decision Altitude (600ft)		
• ~600ft AGL • If the pilot has not determined to land and disengaged the autopilot, the aircraft will automatically execute a missed approach.		
“DA” or “Minimums”	PNF	Discrete
if not determined to land “Missed approach point	PNF	Discrete
if not determined to land “Going around”	PF	Discrete
500 Foot Call-out		
• 500ft AFE • This is a stabilization gate at which the speed, descent rate and flaps must all be configured for landing.		
Either automatic or called “500”	PNF	Discrete
States speed relative to bug, descent rate and final flaps	PF	Discrete
100ft Call out		
• ~100 ft AGL • ~10 seconds		
Call out 100ft	PNF	Discrete
Flare and Wheel Touch		
• ~30 ft AGL • ~117 kts		
Flare and let AC settle onto main landing gear	PF	Discrete

5.2.2.2 Non-sequential Events and Tasks

Event / Task Description	Operator	Type
Transition from Automatic to Manual Flying		
• This event will occur once during the approach and landing phase. The PF will determine when to begin manually flying the aircraft. This is usually associated with being able to see the runway. • Once the PF begins flying manually, his attention will be out the window making sure he's aligned with the runway. The PNF will monitor the instruments and perform the required call-outs from the point where the PF began manually flight.		
Press autopilot disengage button. Turn off alarm.	PF	Discrete
Monitoring Flight Path and Progress		
• This task is ongoing throughout all phases of flight and consists of periodic instrument scans. The crew will periodically look at the ND display to determine that the aircraft is traveling along its assigned path and at the PFD to determine that the aircraft is at its assigned altitude and appropriate attitude. While the ND and PFD are the primary instrument displays used by the crew other instruments will occasionally be included in periodic scans.		
Monitor ND	Both	Intermittent
Monitor PFD	Both	Intermittent
Monitor other control instruments	Both	Intermittent
Monitoring the Party Line		
• This task occurs throughout all phases of flight but neither constant nor intermittent attention is required but is, instead, directed when a voice is heard over the headset. • Can be almost continuous when line communication is very busy.		
Monitor Headset	Both	Intermittent/ Discrete
Monitoring AC Systems		
• This task occurs throughout all phases of flight. However, while the crew will periodically scan the system displays looking for abnormalities, the aircraft systems will flag or otherwise announce system problems to direct the crew's attention.		
Monitor system displays	Both	Intermittent

Figure 8 shows the procedural sequence for the RNAV approach set out along a time, distance and elevation profile. The times, distances and elevations are approximations and are not displayed to scale in this figure. Rather the figure is simply another method of displaying the sequence of tasks during the approach.

RNAV Approach

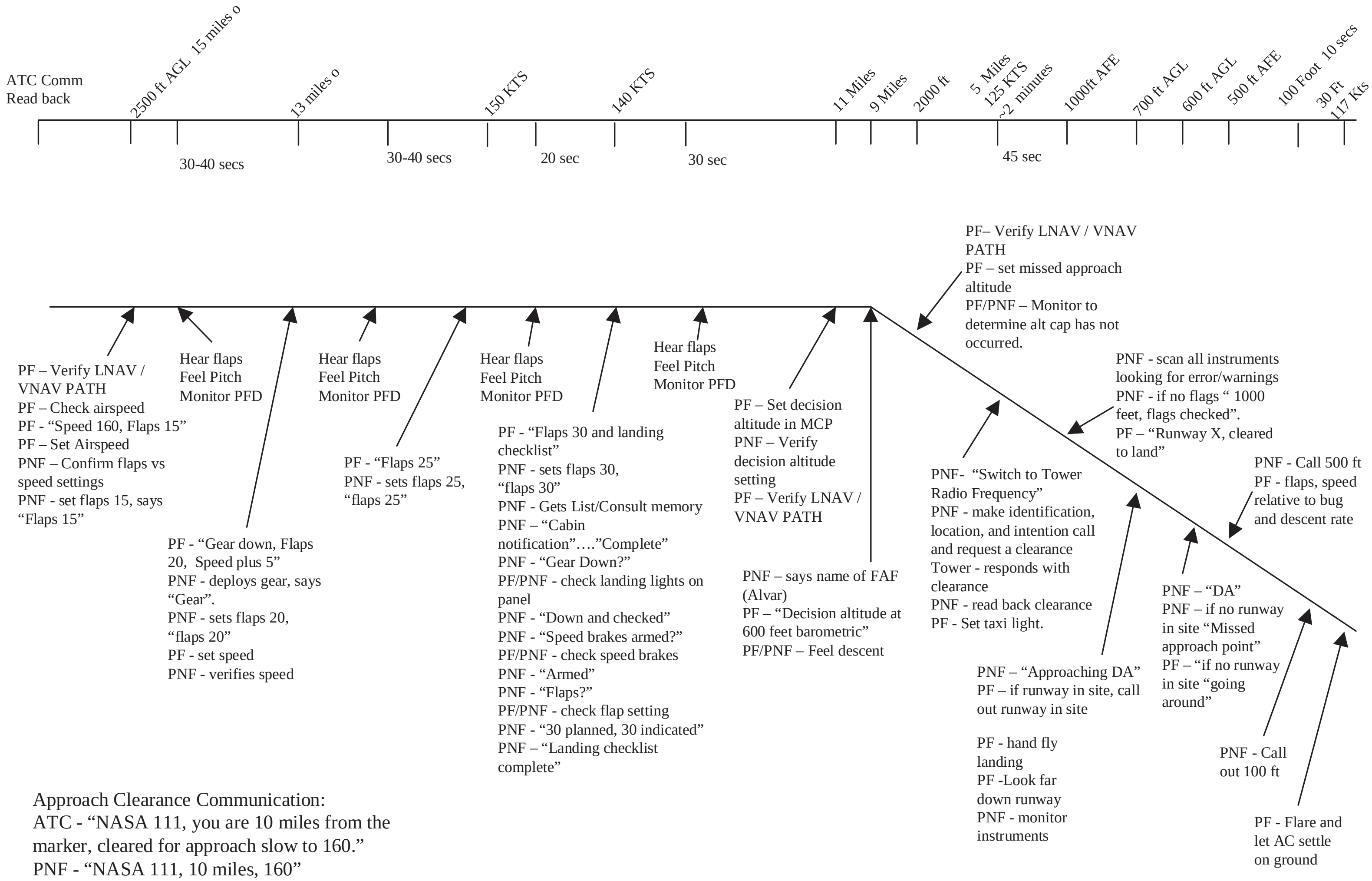


Figure 8. RNAV Approach Procdural Sequence

5.3 RNAV-Based Simulation

The simulator used by NASA Ames for the SVS comparison situational awareness tests simulated RNAV approaches as the baseline component. They developed an RNAV approach plate and procedure for the Santa Barbara Municipal Airport (SBA) to use for the simulation. Figure 9 shows this approach plate. The approach is designed to land on runway 33L from the west such that any missed approach will have to be made towards the mountains thus introducing the issue of terrain into the experiment. The elevations and distances are somewhat different than the approach described in the task analysis in this document. However the differences should not affect the modeling teams very much. In general the approach is conducted at a lower altitude with slightly less distance between some of the waypoints. This will force the pilots to compress their actions somewhat to fit within the time allowed. The rest of this section will describe specific differences and how to combine them within the task analysis if the modeling teams choose to use the details of this approach during their modeling efforts.

The DA of 650ft can be found in the lower left corner of the approach plate and the missed approach altitude of 5000ft can be found in the upper right corner. The approach plate describes beginning the process from the GAVIOTA waypoint up the coast from SBA. The approach continues to LOBER descending to 3000ft then on to the FAF at GOLET descending to 1800ft and initiating the final descent towards PHANTOM and on to runway 33L. To match this approach with that of the task analysis, start from a point at least 5 miles before GOLET and assume that the FAF at GOLET corresponds to the ALVAR waypoint from the task analysis. The plane should be flying level at 1800ft (or reach 1800ft well before GOLET) and the aircraft should be fully configured through the landing checklist at least one mile prior to GOLET. At this point the crew would reset the MCP altitude to a DA of 700ft. The approach plate indicates that the DA for an LNAV/VNAV approach is 640ft but the crew will have to round up to the nearest 100 since the MCP altitude setting does not include tens of feet. The final descent will begin as they cross GOLET. Once they are established on the approach, the crew would set the missed approach altitude of 5000ft by spinning the MCP altitude dial to prevent altitude capture. The identification call to the tower will probably take place prior to reaching PHANTOM as it is only 3.1 miles from the runway. The 1000 ft callout should occur crossing PHANTOM and since the DA is set at 700ft, the ‘Approaching DA’ event will have to occur about 800ft.

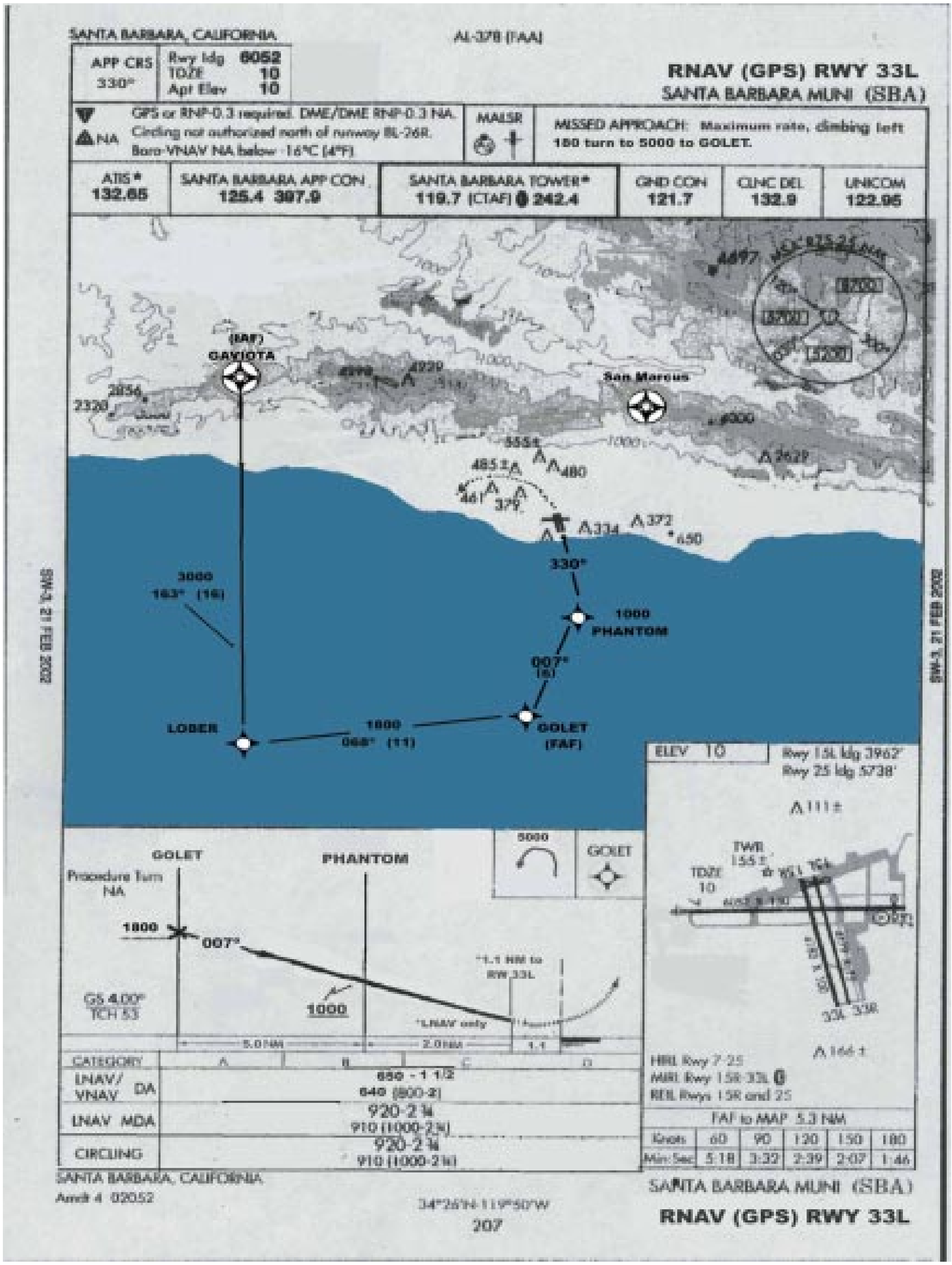


Figure 9. Santa Barbara RNAV approach plate used for simulation

5.4 Problems and Errors

Many accidents and incidents associated with the aircraft industry are related to chains or sequences of problems. Some of the problems that are part of these chains are known as latent errors that were committed or occurred either well before or early in the flight and compound or create problems later on in the flight. Although these errors and error chains are important in terms of aviation safety, the focus of this research has been on the approach and landing phases of flight. In addition, the modeling efforts that will stem from this study will focus on comparisons of equipment used primarily during approach and landing. As such, the errors discussed in this section are limited to those that can occur during the approach and landing phases.

The most common errors during the approach are associated with planning and timing. One of the main differences between the 757 and other aircraft types is the difficulty in slowing down. While the wing and engine combination of the 757 allow it to fly very well, they make it harder for the crew to slow the aircraft within the limited confines of the approach phase. As a result, it is important for the crew to be particularly aware of the speed and altitude versus distance from the airport in order to prevent the common problem known as ‘coming in high and fast’. As such, the crew must be planning and thinking ‘ahead’ of the plane. Problems often occur when the crew gets ‘behind’ the aircraft such that they are rushed to get slowed and configured properly. The most common consequence of such problems is to incur a missed approach. However, the stress of time pressure can result in inattention to specific flight controls and a loss of situational awareness. Such problems have resulted in crashes or near crashes known as controlled flight into or towards terrain.

5.4.1 RNAV Specific Errors

The following errors are specific to RNAV-type approaches. In each case they relate changes in the automatic flight modes based on actions or inactions by the crew.

<u>Lateral Navigation</u>

The LNAV mode keeps the aircraft on the lateral course to the next waypoint programmed in the FMC. It will take into account any required heading changes in order to reach the active waypoint. Small heading changes might be required due to cross winds pushing the aircraft sideways. If the aircraft is in the Heading Select mode rather than LNAV, the aircraft will follow the heading set in the MCP without accounting for any cross winds. In this situation, the aircraft while still on the correct heading might not be heading directly towards the next waypoint. If VNAV is engaged with Heading Select, then the vertical profile of the approach would continue to allow the aircraft to descend while laterally they might not be where they intended. There are no system warnings to prevent or recover from this error. Only the period check of the instruments to determine LNAV is active during an RNAV approach would catch this error while in IMC. Certainly the crew would identify any lateral location problems when breaking out below the cloud deck. However, if this error is combined with terrain issues along the approach path the crew might get a ground proximity warning during the descent if the aircraft has strayed off course near higher terrain. This situation is potentially serious in IMC since the crew is not expecting to have a problem with terrain and may not realized they have strayed off course.

Failure to set Decision Altitude

Prior to reaching the FAF the crew must set the DA in the MCP. In the example from the task analysis, the aircraft is flying level at 2500ft approaching the FAF at Alvar. If they do not set the 600ft DA in the MCP prior to reaching Alvar, the aircraft systems will transfer to the Altitude Hold mode and drop out of VNAV PATH. Although LVAV will continue to institute any programmed heading changes, the aircraft will continue to fly at 2500ft. The cockpit systems provide some help to prevent this situation. Prior to reaching a waypoint where a change in elevation is programmed an ICAS message will occur requesting the crew to reset the MCP altitude. This message is presented on the ICAS system display but does not include an aural annunciation. The crew would also most likely notice that the descent has not begun as expected after passing through the waypoint.

Setting wrong Decision Altitude

If the crew does set a DA prior to reaching the FAF waypoint it is still possible to set an incorrect altitude into the MCP. If they set an altitude that is higher than the desired DA, the aircraft will execute a missed approach sooner than expected by the crew. If the crew is able to quickly diagnose the problem they will then have to decide whether or not to continue with the missed approach or take manual control of the aircraft. If they are not able to diagnose the problem quickly, they will most likely continue with the missed approach. If they set an altitude that is lower than the desired DA and they do not break out below the cloud deck prior to reaching that altitude, the aircraft will execute the missed approach but at a lower altitude than the programmed DA. The consequences of this depend on how low the aircraft has gotten relative to terrain before beginning the missed approach procedure. As previously discussed, RNAV approaches usually aren't used when the cloud deck is very near the published DA so it is likely that the aircraft would break out before or near the published DA an take manual control prior to reaching the mis-programmed DA.

Failure to set Missed Approach Altitude

Once the aircraft is stabilized on the final descent above the DA, the crew needs to set the missed approach altitude in the MCP so that the aircraft systems will execute the correct missed approach procedure at DA. If the crew fails to reset the MCP, the aircraft systems upon reaching the DA will revert to Altitude Hold. In the scenario from the task analysis, Alt Hold would occur at 600ft. The aircraft would perform the missed approach procedure including any programmed turns but it would only level out at 600ft rather than climbing. At first, the aircraft would feel like it was performing the missed approach properly. The aircraft would stop descending and the throttles would move forward. However, they would not begin climbing. The problem from the crew's perspective is one of identification. They would be expecting the aircraft to halt the descent and bring the throttles up and at first these expectations are not violated. They might even feel as though they are climbing which is what they would expect. To begin to identify the problem in IMC, they would have to either feel that the aircraft is not climbing or they would have to get this information from the instruments.

Altitude Capture while setting MCP to Missed Approach Altitude

While spinning the MCP altitude dial to set the missed approach altitude it is possible that the aircraft systems could revert of Altitude Capture. That is, if there is a pause or slowing while spinning the dial, the aircraft may capture an altitude between where it was set and the final setting the crew intended. In the scenario from the task analysis, while the aircraft is descending from 2500ft and the crew tries to reset the MCP from the 600ft DA to the 4000ft missed approach altitude the aircraft might capture an altitude of 1500 for example. If this occurs, the systems will revert to Altitude Hold upon reaching 1500 and level off at that altitude. The flight mode annunciators will switch to Alt Capture then to Alt Hold and the altitude hold light on the MCP will come on. Per procedure, if VNAV PATH is lost during this final descent and not in VMC, the crew must execute a missed approach.

5.4.2 Generic Errors

The following errors are specific to the approach phase of flight but are not specific to either ILS or RNAV approaches.

Aircraft Spacing

Spacing errors become a problem as ATC tries to prescribe aircraft locations and require maneuvers that may be difficult or impossible for the crew to perform. Problems can occur when ATC asks the crew to maintain a particular speed when they really need to be slowing or when they are asked to maintain spacing behind and aircraft they know can slow down faster than the 757. It is up to the crew to keep out of bad situations. The pilots use TCAS and information from the party line to maintain their awareness and spacing from other AC. The results of errors can be illegal spacing between aircraft or coming in ‘high and fast’. Both these situations can incur a missed approach.

Stabilization Gates

The crew must be able to hit particular stabilization gates. That is, at certain locations during the approach, the crew must have achieved a certain attitude and speed in order to continue the approach. By 1,000 ft AGL the speed, sink rate and alignment suitable for landing ‘should’ be achieved. If the aircraft is not stable at a speed of about 130 kts, a sink rate of about 700 ft per minute and properly aligned within the localizer or in visual contact with the runway then a missed approach is mandatory. The airspeed varies a little with landing weight and the groundspeed will vary some with the wind. Sink rate can vary somewhat with groundspeed. Some airlines require stabilization by 1000ft while others require it at 500ft. Many pilots use the general rule of 1000ft if they are having trouble stabilizing the aircraft for final approach.

Speed Brakes

For each of the last three problem areas there is some help on the 757. If the pilot flying finds that they are coming in too high and/or fast, he has the option to use the speed brakes. On all aircraft the speed brakes (or spoilers) are flaps on top of the wing. When they are deployed they lift up and not only catch air to slow the plane down but also destroy the lift created by the wing allowing the aircraft to lose altitude. On the 757 the use of the speed brakes is part of the standard procedure during approach and landing. The pilot flying can deploy the speed brakes for a short period to help the autopilot achieve a necessary altitude and/or speed requirement. While the use of the speed brake is common practice for the 757 there are also problems associated with its use. The primary error is to forget that they are deployed and try to land. They will induce a high sink rate and increased deceleration that the autopilot and auto throttle may try to make up for. In addition, if the speed brakes are deployed during landing, a tail strike is likely to occur upon flaring the aircraft.

FMC Reprogramming

Another problem relates to the reprogramming of the FMC. Due to weather or other concerns, the ATC may change the approach plan expected and programmed into FMC by the crew. Such changes can occur at any point during the flight and can be a common occurrence at crowded airports. If a change is made, the crew will want to reprogram the FMC to reflect the new flight plan. The general rule is that you should not attempt to reprogram an approach if you are below 10,000ft. The problem is that there may not be enough time to make the changes and still perform the necessary slowing and configuration tasks. In addition, the attention of the crewmember working with the FMC is directed down and away from other instruments and the cockpit windows. This can translate to errors of attention in which the crew fail to monitor course changes or aren't able to achieve a proper stabilization gate.

Radio Frequency

Approach frequency errors of the communication and navigation radios can also occur. This happens usually as a result of haste, the failure of a second check, or through slips and the flipping of digits. Such errors are usually caught with sufficient crew resource management practices. Also, if two navigation radios are set to mismatched frequencies then warning flags will alert the crew. However if both crewmembers fail to set the radios or make appropriate changes there are no flags to alert them to the problem. Unlike the navigation radios, there are no alarms for the communication radios. Usually, upon tuning a radio or flipping the frequency setting switch, the crew will initiate a call or hear other communication. If no communication is heard or there is no response, the crew will return to the previous frequency (approach control) to get frequency clarification. The consequences of errors setting the communication radios can range from simply not getting the information required to reach a stabilization gate thus incurring a missed approach or more serious issues of spacing in heavy traffic patterns. Consequences of errors setting the navigation radio frequencies can result in failing to capture the localizer and incurring a missed approach.

Distractions

Distractions are not uncommon during flight. There are many things that can divert the crew's attention from a current task. Some of these are events or issues that must be attended to while others can represent simple nuisances. If a pilot becomes distracted, he may or may not remember to return to the task he was performing or may not be able to complete it in a timely manner. Other distractions may function as performance shaping factors that make normal tasks more difficult. Changes made by ATC to the flight plan can become distractions. This is especially true if the aircraft is close to the airport and the crew has to make changes either to the FMC and/or to their own awareness and planning during an already busy phase of flight. A high volume of communication traffic on the party line can distract the crew from other tasks as they attempt to comprehend all the information that is being presented. Periods of high air traffic associated with the approach phase at busy airports will also provide distractions as the crew attempts to maintain visual contact and spacing from aircraft near by. Weather can actually cause more distractions when it is minor. Serious weather that limits visibility we result in a change in the aircraft spacing rules and runways that are used. However, light weather that is on the edge of VFR conditions may make it difficult to carry out expected visual tasks such as identifying other nearby aircraft. Likewise, approaches and landings done at night over large brightly lit areas can make it difficult to see lights of other aircraft and the airport as their identifying lights are lost in the high light background. Finally, equipment problems or failures can represent serious distractions depending on the system, severity of the problem, and phase of flight.

6 Recommended Reading

Fundamentals of Air Traffic Control by M. Nolan
Provides an excellent description of RNAV, ILS, instrument approach procedures, runway lighting, and ATC communication phraseology.

Key Cognitive Issues in the Design of Electronic Displays of Instrument Approach Procedure Charts, Monterey Technologies.
The main document doesn't apply specifically to HPM of the approach, but it has a very interesting 34 page appendix, which actually includes a Conceptual Graph Structure of the ILS approach. Also contains a high-level task analysis.

The Pilot's Guide to the Modern Airline Cockpit by S. Casner.
Hot-off-the-press, this "technical, but doesn't read that way" book explains very clearly the next generation flight deck with an emphasis on the FMS and guidance modes.

Situation Awareness Requirements for Commercial Airline Pilots by M. Endsley et al.
This paper breaks SA requirements down by phase of flight
(included to modelers electronically)

Priority and Organization of Information Accessed by Pilots in Various Phases of Flight by Schvaneveldt et al.
Provides insight into what information is most important to pilots, decomposed by flight phase.
(included to modelers electronically)

Understanding a Pilot's Tasks by P. Ververs.
Similar to above, with a slightly different emphasis
(included to modelers electronically)

7 Acknowledgements

The authors would like to thank Rick Shay from United Airlines for his support with the cognitive task analysis.

8 Acronyms

ADI	Attitude Display Indicator
AGL	Above Ground Level
ATC	Air Traffic Control
AvSP	Aviation Safety Program
CDU	Control Display Unit
FAF	Final Approach Fix
FD	Flight Director
FMC	Flight Management Computer
FMS	Flight Management System
FO	First Officer
GSIA	Glide slope intercept altitude
HPM	Human Performance Modeling
HSI	Horizontal Situation Indicator
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
KIAS	Knots Indicated Air Speed
Kts	Knots
LNAV	Lateral Navigation
MCP	Mode Control Panel
ND	Navigation Display
OM	Outer Marker
PF	Pilot Flying
PFD	Primary Flight Display
PNF	Pilot Not Flying
RNAV	Area Navigation
SA	Situation Awareness
SBA	Santa Barbara Municipal Airport
SME	Subject Matter Expert
STAR	Standard Terminal Arrival Route
SVS	Synthetic Vision System
TCAS	Traffic alert and Collision Avoidance System
VASI	Visual Approach Slope Indicator
VMC	Visual Meteorological Conditions
VNAV	Vertical Navigation

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